Engine Starts and Soaks Data Collection and Analysis

- Evaporative Emissions **Run & soak**
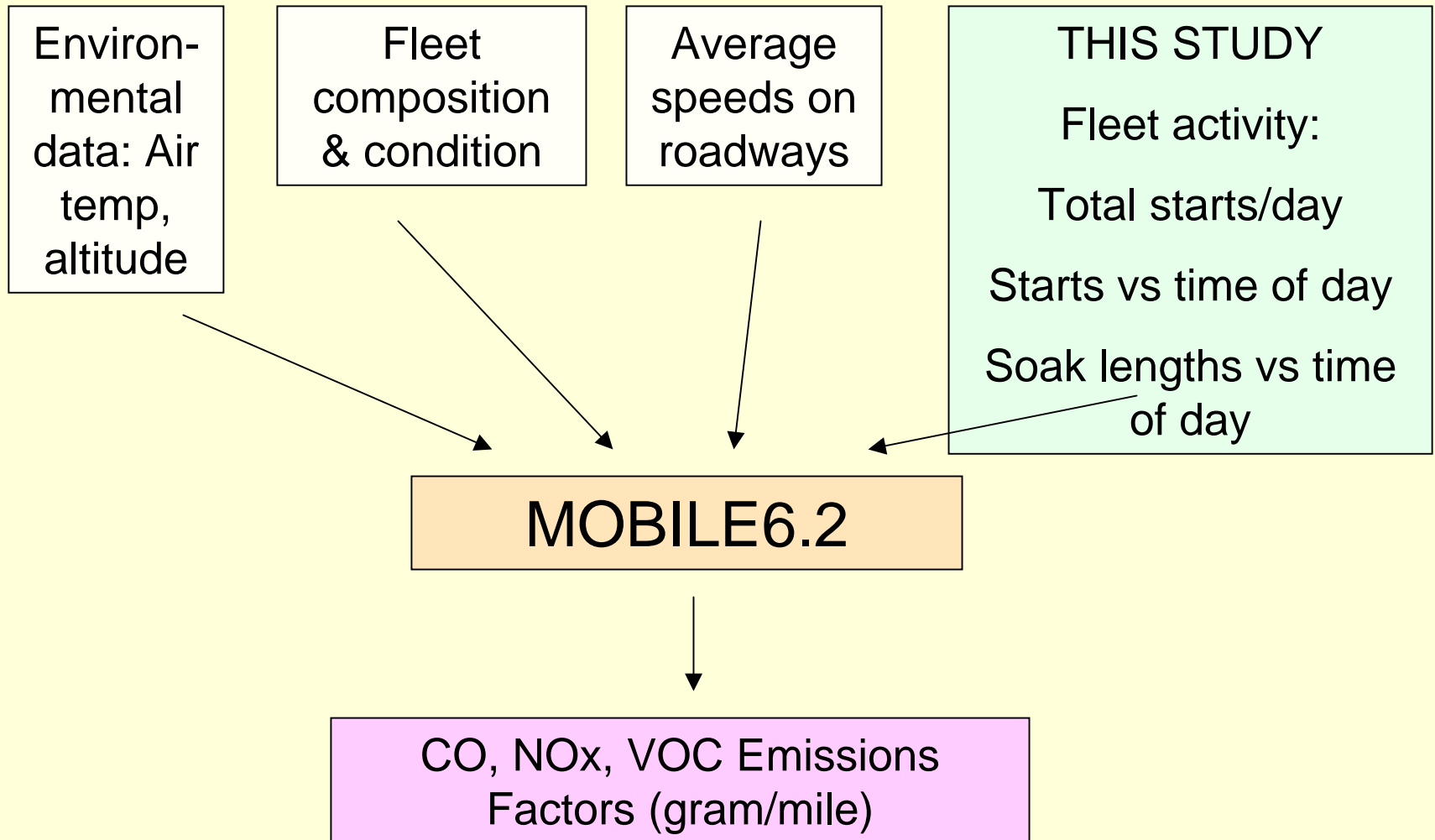- Refueling Losses **Soak**
- **Start & Run**
- Exhaust Emissions

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UNLV Civil & Environmental Engineering

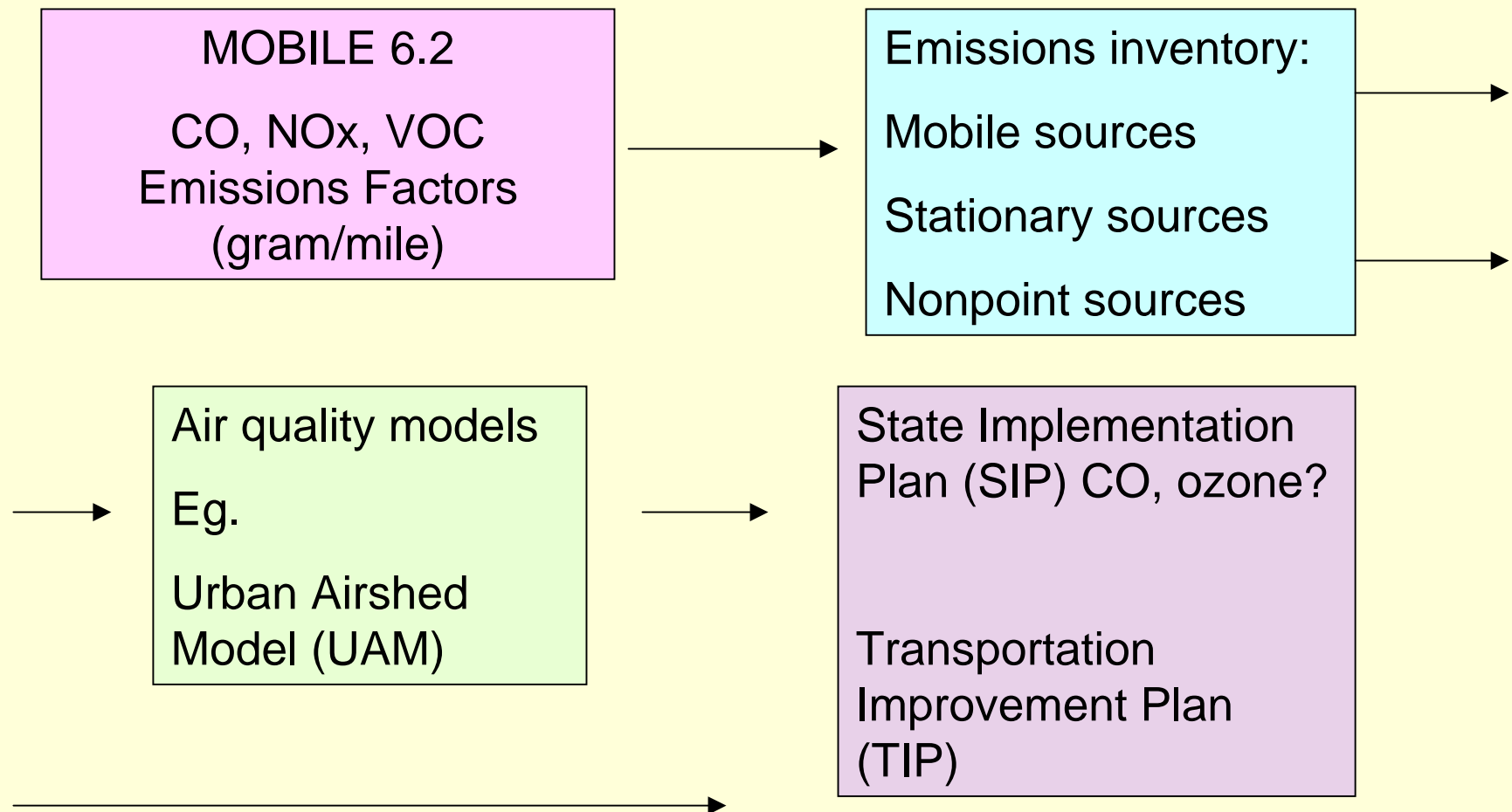**Clark County Air Quality Forum – 8 Nov 2005**

Goal of study

- Develop <u>local input files</u> for amount and distribution of engine starts and soaks
  - To be used in EPA MOBILE6.2 emissions model
  - Local input files replace national defaults to generate more accurate mobile source VOC, NOx and CO emissions estimates

MOBILE6.2 model inputs

| Environ-mental data: Air temp, altitude | Fleet composition & condition | Average speeds on roadways | THIS STUDY

Fleet activity:

Total starts/day

Starts vs time of day

Soak lengths vs time of day |

MOBILE6.2

CO, NOx, VOC Emissions Factors (gram/mile)

How MOBILE 6.2 outputs used

MOBILE 6.2

CO, NOx, VOC
Emissions Factors
(gram/mile)

Emissions inventory:

Mobile sources

Stationary sources

Nonpoint sources

Air quality models

Eg.

Urban Airshed
Model (UAM)

State Implementation
Plan (SIP) CO, ozone?

Transportation
Improvement Plan
(TIP)

Project phases & status

- Pilot Studies: October & December 2004

- Random study: 500 contacts -> 133 participants: February-April 2005

- Corporate/RTC: 216 participants: November,'04-May. '05

- Data reduction, analysis and report – June '05-present – report now being written

Participant classifications

Participant type	Number	Proportion
Random digit dialing	133	38%
Government	34	10%
Corporate, other private	161	46%
UNLV	21	6%
Total	349	100%

Summary: Random sample comparison to census

| Category	Comparison (statistical tests for significance not yet performed) random vs census
Age	Lower proportion 18-34 (11% vs 28%) Higher proportion: $\geq$ 60 (39% vs 27%)
Employed	Slightly lower proportion employed (65% vs 67%)
Gender	Slightly larger proportion female (54% vs 49%)
Employment categories	Higher professional services (29% vs 11%) Higher education/healthcare (19% vs 9%) Lower government (5% vs 11%) Lower hotel/gaming (14% vs 33%)

Fleet composition in study

- Surveyed in this study
  - Privately-owned gasoline powered
    - passenger cars and
    - light "trucks" – pickups, vans, SUVs
- Not surveyed in this study
  - Privately owned diesel vehicles
  - Fleet vehicles
    - Taxis, delivery vehicles, rental-cars, motor pools
  - Buses and heavy trucks
  - Off-road equipment

Where the sensor goes – 12v power tap/cigarette lighter
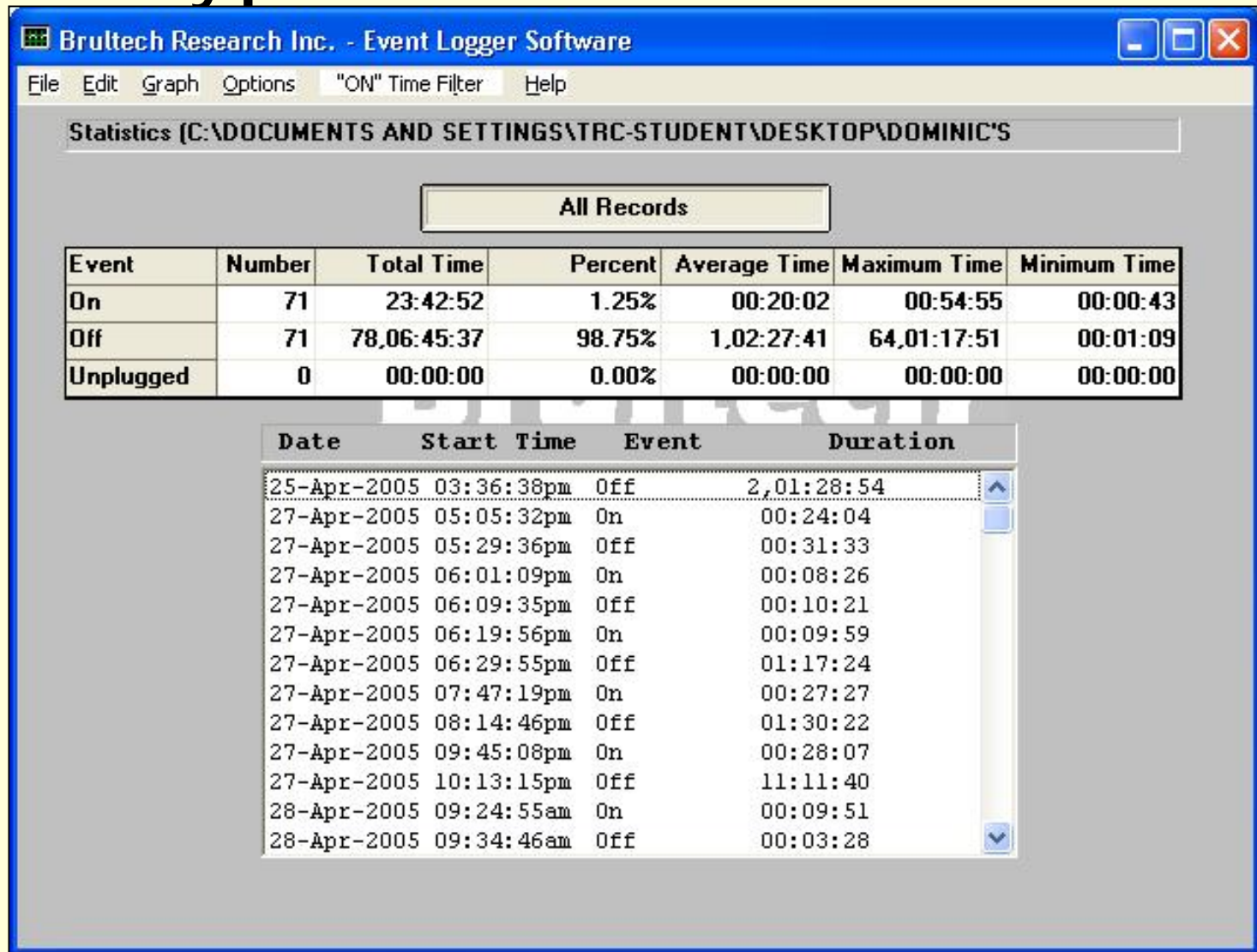

12v outlet

How start sensor works
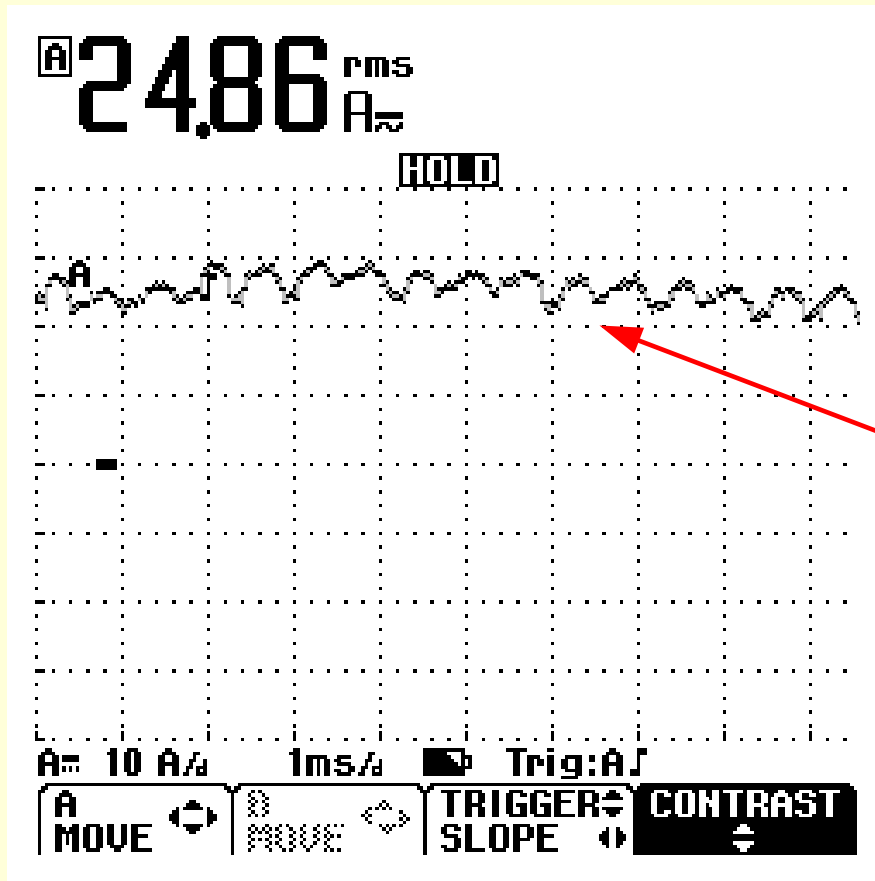
- Some 12V outlets "off" & others "on" with key off

- Sensor detects "ripple" in alternator output when engine running
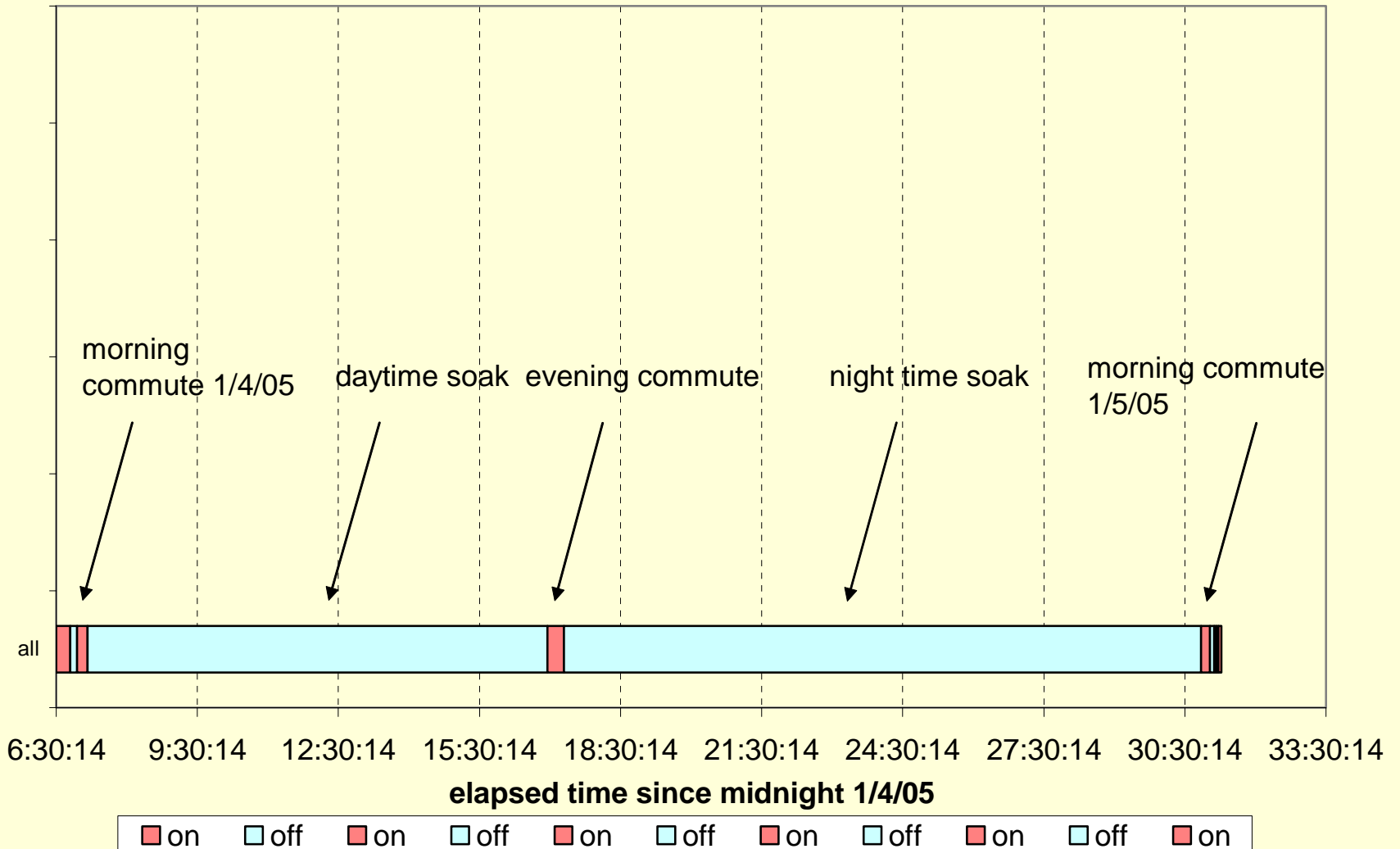
- Sensor filters out smaller stray radio spikes

http://www.autolabscopediagnostics.com/alt.html - accessed 11/7/05

Typical sensor data file

Brultech Research Inc. - Event Logger Software

File Edit Graph Options "ON" Time Filter Help

Statistics (C:\DOCUMENTS AND SETTINGS\TRC-STUDENT\DESKTOP\DOMINIC'S

All Records

Event	Number	Total Time	Percent	Average Time	Maximum Time	Minimum Time
On	71	23:42:52	1.25%	00:20:02	00:54:55	00:00:43
Off	71	78,06:45:37	98.75%	1,02:27:41	64,01:17:51	00:01:09
Unplugged	0	00:00:00	0.00%	00:00:00	00:00:00	00:00:00

Date	Start Time	Event	Duration
25-Apr-2005	03:36:38pm	Off	2,01:28:54
27-Apr-2005	05:05:32pm	On	00:24:04
27-Apr-2005	05:29:36pm	Off	00:31:33
27-Apr-2005	06:01:09pm	On	00:08:26
27-Apr-2005	06:09:35pm	Off	00:10:21
27-Apr-2005	06:19:56pm	On	00:09:59
27-Apr-2005	06:29:55pm	Off	01:17:24
27-Apr-2005	07:47:19pm	On	00:27:27
27-Apr-2005	08:14:46pm	Off	01:30:22
27-Apr-2005	09:45:08pm	On	00:28:07
27-Apr-2005	10:13:15pm	Off	11:11:40
28-Apr-2005	09:24:55am	On	00:09:51
28-Apr-2005	09:34:46am	Off	00:03:28

Terminology

- Start – *Engine "on" event exceeding 30 seconds*
- Soak – *initiated by engine "off" event*

Pollutant	CO	NOx	VOC
Start & run emissions	XX	XX	XX
Soak emissions			XX

Example graph: one-day start record
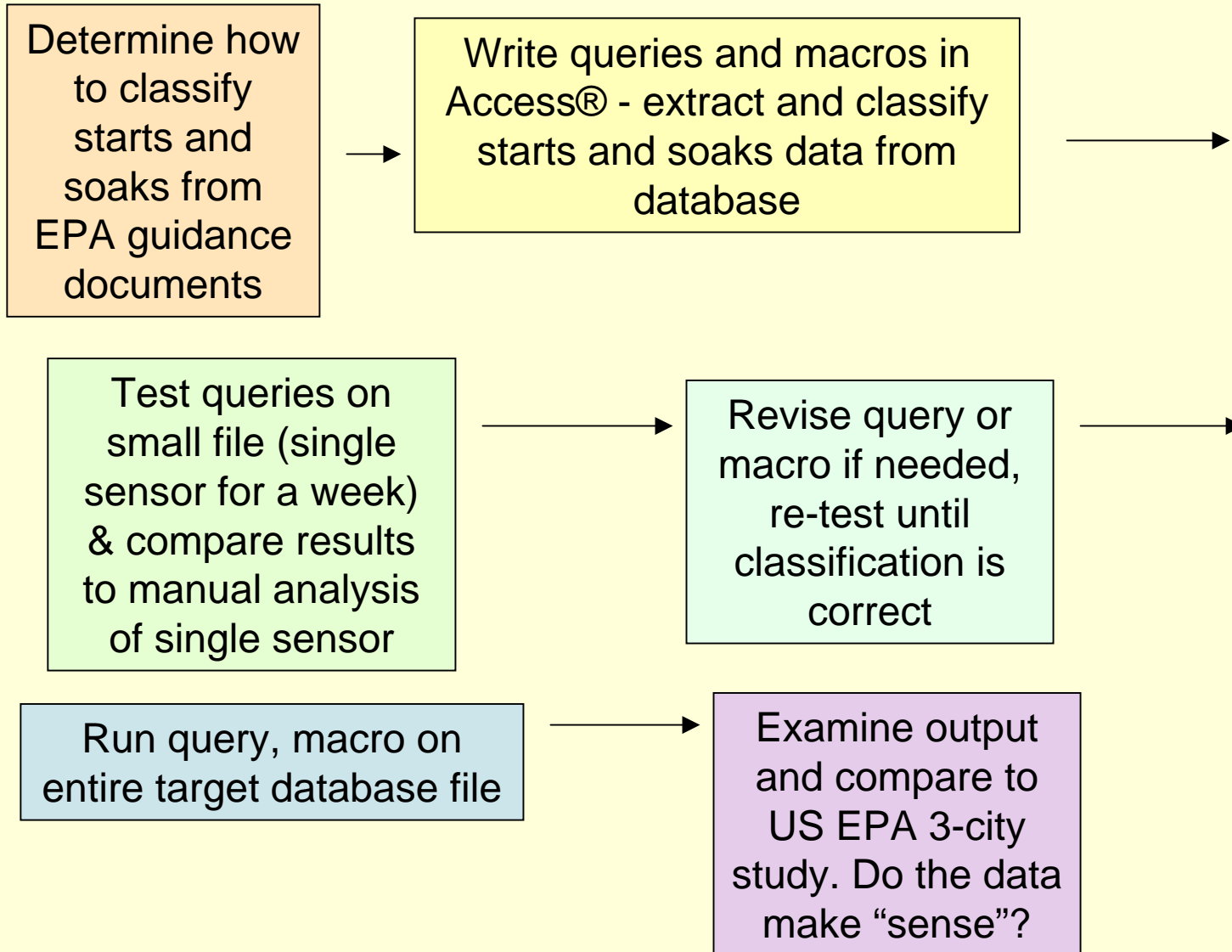
Typical commuter start/soak activity pattern - 3 starts/day

morning commute 1/4/05

daytime soak

evening commute

night time soak

morning commute 1/5/05

all

6:30:14 9:30:14 12:30:14 15:30:14 18:30:14 21:30:14 24:30:14 27:30:14 30:30:14 33:30:14

elapsed time since midnight 1/4/05

□ on □ off □ on □ off □ on □ off □ on □ off □ on □ off □ on

Sensor data processing

- "Start" definition – EPA
  - Early 1990's EPA study – Spokane, Baltimore, Richmond VA
  - Start defined as any Key–on event with a duration greater than 30 seconds
  - Key-on events < 30 seconds screened from EPA database
- UNLV-RTC study
  - Calibrated all 120 Brultech sensors to factory specs
  - Applied same 30-second event-screening criterion as EPA
  - Tested validity of 30-second event screen using 9-car, 85 event-day sample comparing Brultech to digital OBD II sensors
  - 30-second filtration of Brultech data gave best match to OBD-II sensor data.

Data processing - I

Brultech software - filter sensor data file to eliminate "false" events. Save as ASCII file (349 files)

→

Import to MS Excel® workbook Identify hot/cold, assign soak codes, develop daily summaries

→

Consolidate Excel® workbooks into MS Access® database (28,385 records)

→

Run Access® queries and macros classify starts/soaks into frequency bins Save to tables

→

Export Access® frequency tables to MS Excel®, calculate frequencies

→

Format results for MOBILE6.2 input files and generate graphical outputs

Data processing II - Algorithm testing

Determine how to classify starts and soaks from EPA guidance documents

→

Write queries and macros in Access® - extract and classify starts and soaks data from database

→

Test queries on small file (single sensor for a week) & compare results to manual analysis of single sensor

→

Revise query or macro if needed, re-test until classification is correct

→

Run query, macro on entire target database file

→

Examine output and compare to US EPA 3-city study. Do the data make "sense"?

Compared to EPA 3-city study, Las Vegas shows, for Starts

- *Fewer weekday starts /day – cars, slightly higher weekend*

- *Fewer weekday & weekend starts /day – light trucks*

- *Higher proportion early AM and late PM starts*

- *Higher proportion of short trips; lower proportion long trips*

Starts/day summary – 1 hour cold start definition

	Las Vegas Hot Starts/day *1 hr soak Avg $\pm$ std dev	Las Vegas Cold starts/day *1 hr soak Avg $\pm$ std dev	Las Vegas Total starts/day *1 hr soak Avg $\pm$ std dev	EPA default Total starts/day Avg
Weekday starts	Cars: 3.0 $\pm$ 3.5 Trucks: 2.6 $\pm$ 2.4	Cars: 2.6 $\pm$ 1.3 Trucks 2.8 $\pm$ 1.5	Cars 5.5 $\pm$3.9 Trucks 5.5 $\pm$ 3.1	7.3 8.1
Weekend starts	Cars: 3.3 $\pm$ 3.8 Trucks: 2.4 $\pm$ 2.0	Cars: 2.4 $\pm$ 1.4 Trucks 2.3 $\pm$ 1.3	Cars 5.7 $\pm$4.4 Trucks 4.7 $\pm$2.5	5.4 5.7

Similar random & non-random starts/day – 1hr soak

	Las Vegas Hot Starts/day Avg $\pm$ std dev	Las Vegas Cold Starts/day Avg $\pm$ std dev	Las Vegas Total starts/day Avg $\pm$ std dev
Cars	Random Dial: 3.0 $\pm$ 3.1 Non-random : 3.2 $\pm$ 4.1 All participants : 3.1 $\pm$ 3.6	Random Dial: 2.5 $\pm$ 1.3 Non-random : 2.5 $\pm$ 1.4 All participants : 2.5 $\pm$ 1.3	Random Dial: 5.5 $\pm$ 3.5 Non-random : 5.7 $\pm$ 4.7 All participants : 5.6 $\pm$ 4.0
Trucks	Random Dial: 2.5 $\pm$ 2.4 Non-random : 2.7 $\pm$ 2.1 All participants : 2.6 $\pm$ 2.3	Random Dial: 2.6 $\pm$ 1.4 Non-random : 2.9 $\pm$ 1.5 All participants : 2.7 $\pm$ 1.5	Random Dial: 5.1 $\pm$ 3.0 Non-random : 5.6 $\pm$ 2.7 All participants : 5.3 $\pm$ 2.9

WeekDAY start distribution
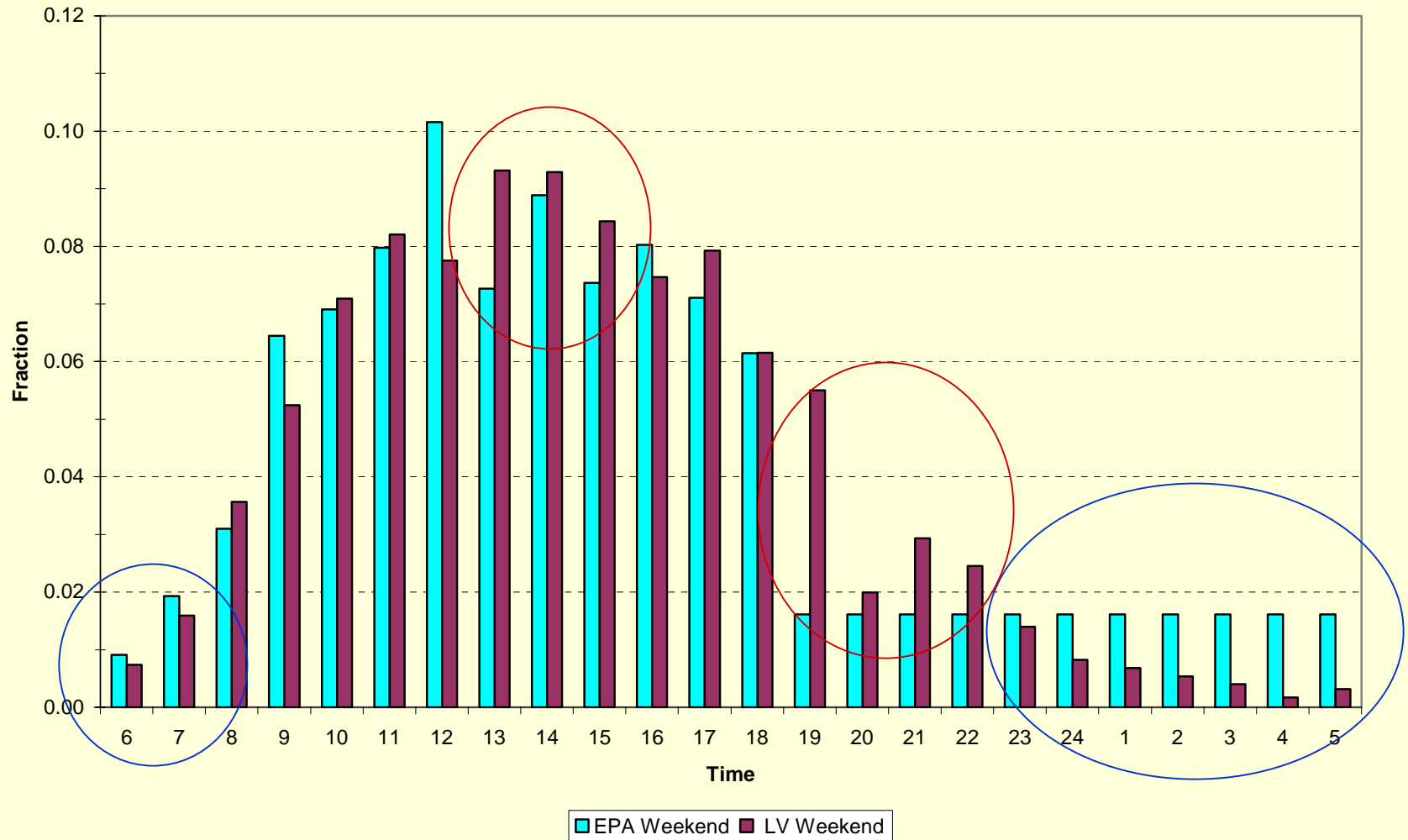# Red – LV higher; Blue – LV lower

Las Vegas vs EPA Weekday Starts Distribution
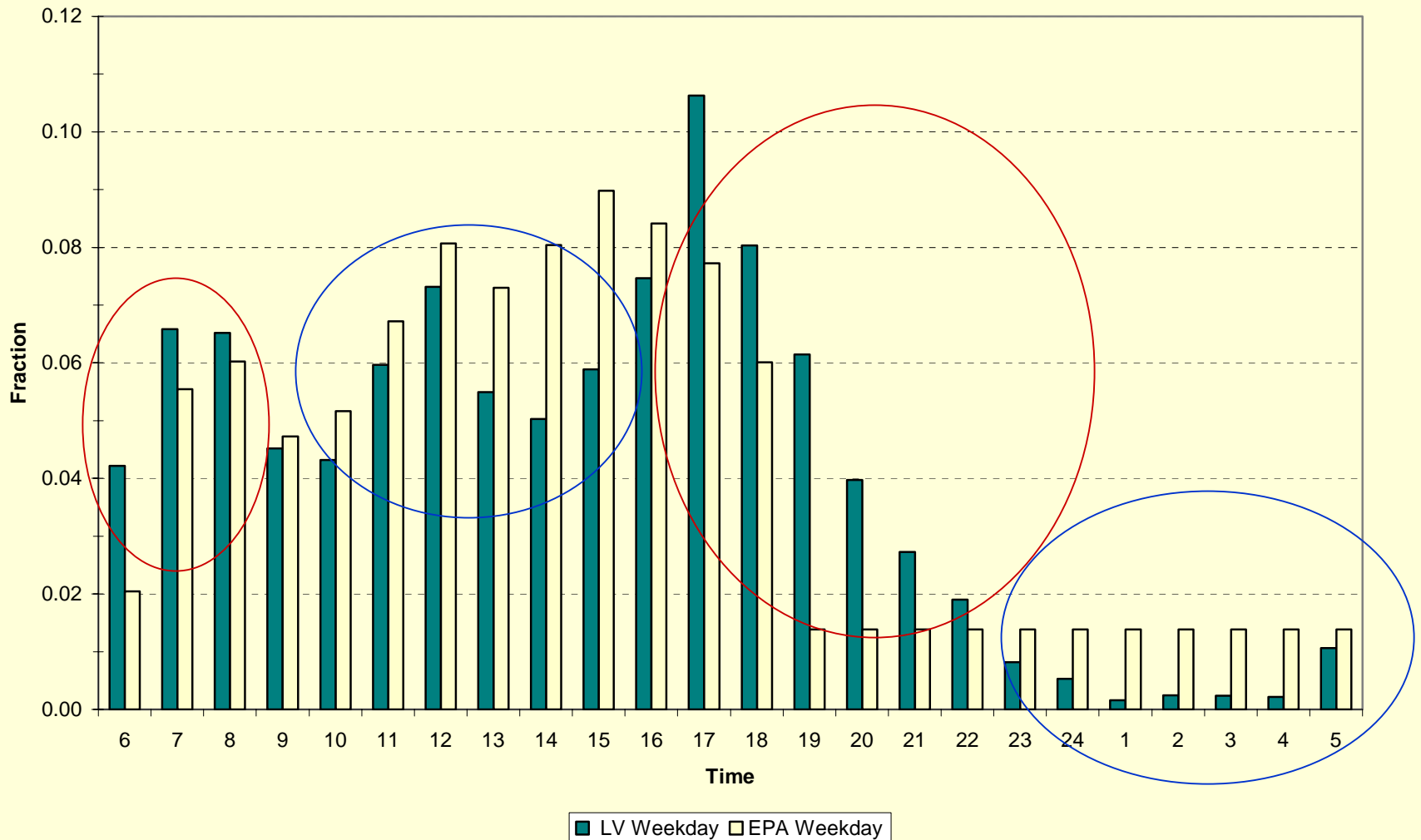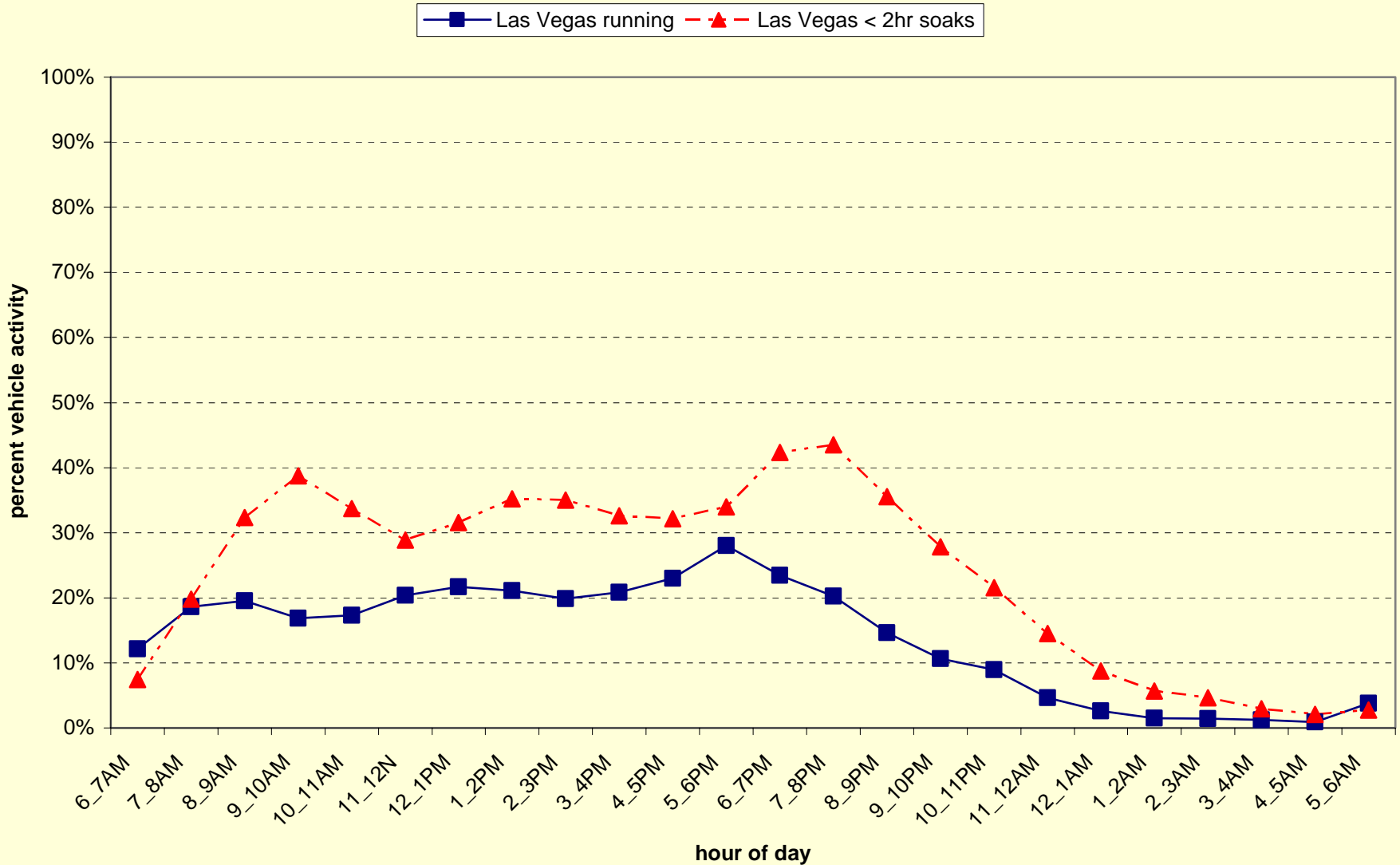
WeekEND start distributions
Red – LV higher Blue – LV lower

Las Vegas vs EPA Weekend Starts Distribution

When do we drive?

Las Vegas engine Running & <2 hr soak activity

■ Las Vegas running ▲ Las Vegas < 2hr soaks

percent vehicle activity vs hour of day

Las Vegas weekDAY trip lengths

trip length (min)	<10	11-20	21-30	31-40	41-50	50+
Hour	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
6	36.7%	29.5%	19.9%	11.4%	2.2%	0.4%
7	35.0%	32.8%	20.2%	8.0%	2.0%	1.9%
8	39.7%	26.6%	21.3%	7.9%	2.4%	2.1%
9	49.1%	30.4%	13.0%	4.3%	1.1%	2.0%
10	56.9%	29.9%	9.1%	3.0%	0.5%	0.5%
11	60.9%	25.1%	10.3%	2.0%	0.8%	0.8%
12	63.2%	24.1%	8.0%	2.4%	0.8%	1.6%
13	56.2%	27.9%	9.6%	3.0%	1.5%	1.9%
14	57.8%	23.9%	12.5%	3.3%	1.4%	1.1%
15	50.1%	26.8%	14.3%	5.3%	1.6%	1.9%
16	44.7%	28.4%	15.9%	6.3%	2.8%	1.9%
17	45.4%	28.0%	14.5%	7.2%	2.9%	2.0%
18	48.5%	26.6%	13.8%	6.8%	2.4%	1.9%
24	52.7%	27.0%	12.9%	4.6%	1.3%	1.5%
average	49.8%	27.7%	14.0%	5.4%	1.7%	1.5%
std deviation	8.8%	2.5%	4.2%	2.7%	0.8%	0.6%

EPA weekDAY trip lengths

trip length (min)	<10	11-20	21-30	31-40	41-50	50+
Hour	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
6	14.9%	22.7%	29.4%	20.8%	12.2%	0.0%
7	16.1%	31.1%	40.0%	9.1%	3.8%	0.0%
8	14.6%	33.5%	18.4%	18.5%	3.0%	12.1%
9	27.4%	32.7%	22.2%	4.8%	0.0%	12.9%
10	28.5%	43.0%	17.1%	7.9%	3.6%	0.0%
11	32.9%	32.8%	15.0%	7.5%	5.3%	6.5%
12	33.4%	39.6%	15.2%	11.8%	0.0%	0.0%
13	28.9%	46.8%	13.9%	9.3%	1.1%	0.0%
14	27.1%	39.3%	18.3%	3.2%	1.4%	10.8%
15	26.8%	41.8%	24.3%	3.9%	2.2%	1.0%
16	24.9%	40.8%	18.8%	10.9%	1.8%	2.9%
17	21.1%	34.8%	29.4%	9.2%	5.4%	0.0%
18	26.8%	32.2%	25.1%	12.0%	3.1%	0.8%
24	21.0%	37.3%	24.5%	7.5%	6.4%	3.4%
average	24.6%	36.3%	22.3%	9.7%	3.5%	3.6%
std deviation	6.2%	6.1%	7.2%	5.0%	3.2%	4.9%

Las Vegas weekEND trip lengths

trip length (min)	<10	11-20	21-30	31-40	41-50	50+
Hour	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
6	51.9%	33.3%	7.4%	0.0%	3.7%	3.7%
7	58.1%	21.0%	16.1%	1.6%	1.6%	1.6%
8	59.6%	25.0%	7.4%	2.2%	4.4%	1.5%
9	57.5%	27.8%	9.4%	3.3%	1.4%	0.5%
10	57.9%	30.2%	8.8%	1.8%	0.7%	0.7%
11	58.5%	24.0%	11.6%	4.7%	0.6%	0.6%
12	49.5%	31.0%	10.0%	5.2%	2.1%	2.1%
13	56.0%	24.7%	10.0%	5.4%	1.5%	2.3%
14	60.4%	23.8%	10.2%	2.3%	1.8%	1.5%
15	56.0%	28.3%	7.8%	3.6%	2.2%	2.0%
16	54.9%	26.6%	10.0%	4.1%	1.6%	2.8%
17	58.6%	25.1%	10.6%	1.5%	2.1%	2.1%
18	54.9%	25.6%	12.1%	3.3%	2.2%	1.8%
24	51.9%	24.8%	13.3%	5.0%	2.2%	2.9%
average	56.1%	26.5%	10.3%	3.1%	2.0%	1.9%
std deviation	3.2%	3.3%	2.4%	1.6%	1.0%	0.9%

EPA weekEND trip lengths

trip length (min)	<10	11-20	21-30	31-40	41-50	50+
Hour	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
6	19.0%	60.6%	20.4%	0.0%	0.0%	0.0%
7	26.9%	42.4%	30.7%	0.0%	0.0%	0.0%
8	20.6%	41.7%	18.8%	0.0%	18.9%	0.0%
9	29.8%	38.3%	23.1%	8.8%	0.0%	0.0%
10	25.6%	42.1%	16.6%	15.8%	0.0%	0.0%
11	27.6%	36.4%	13.3%	10.3%	3.4%	9.0%
12	25.9%	35.5%	28.6%	3.5%	6.5%	0.0%
13	18.4%	19.4%	22.5%	9.9%	4.3%	25.6%
14	23.7%	39.2%	12.3%	14.9%	9.9%	0.0%
15	21.2%	25.4%	25.5%	4.1%	0.0%	23.9%
16	25.7%	25.9%	12.3%	6.6%	15.0%	14.5%
17	24.3%	37.7%	27.3%	3.9%	0.0%	6.8%
18	18.0%	38.4%	18.3%	20.8%	4.5%	0.0%
24	15.7%	27.4%	15.7%	9.6%	2.6%	29.0%
average	23.0%	36.5%	20.4%	7.7%	4.6%	7.8%
std deviation	4.2%	10.0%	6.1%	6.4%	6.1%	10.9%

Compared to EPA 3-city data, Las Vegas shows, for Soaks

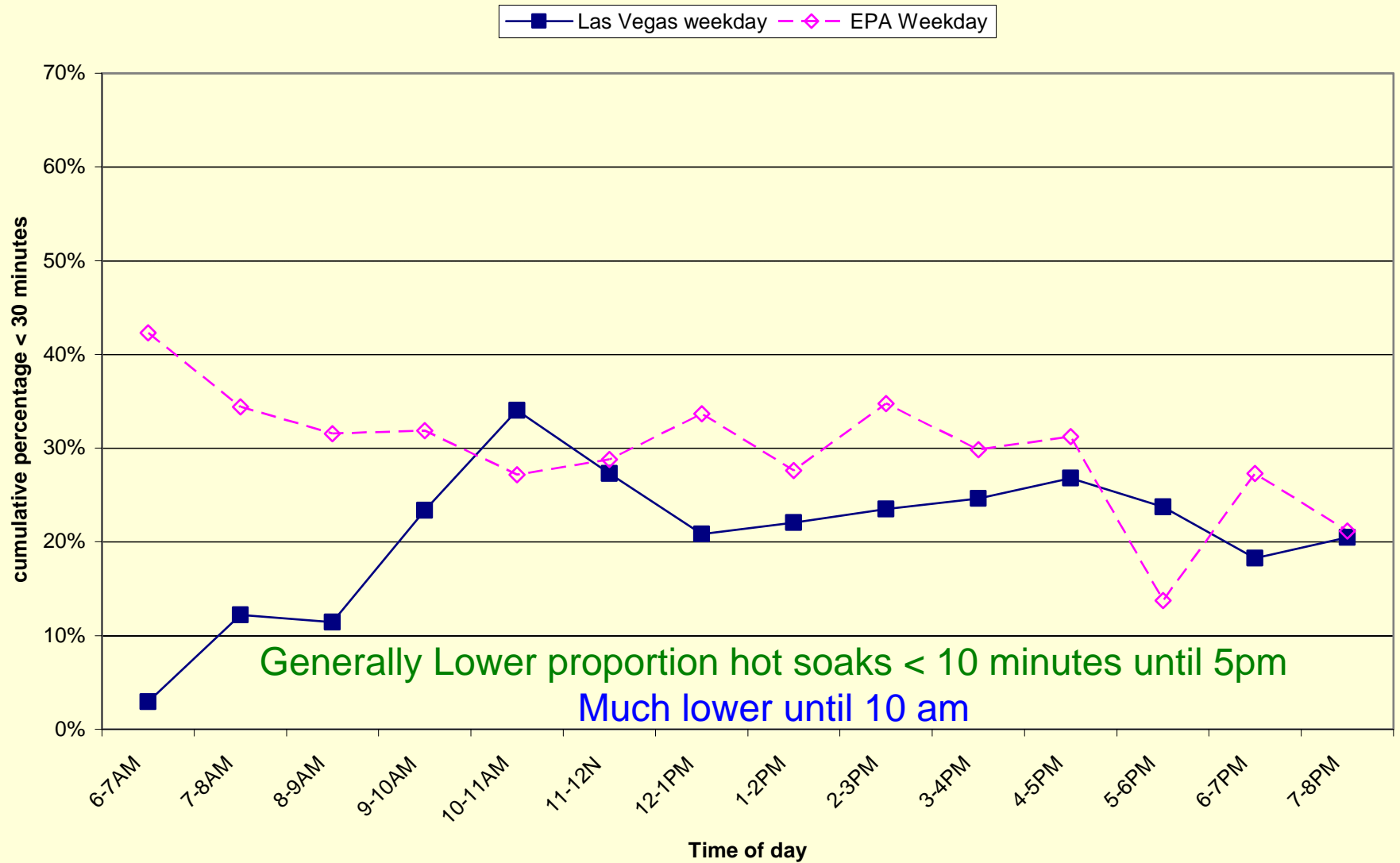| Soak length	Short	Medium	Long
Hot (< 1 hr)	Lower proportion		Lower proportion Higher AM
All (< 12 hr)		Lower prop weekday Higher prop weekend	
Diurnal (< 72 hr) soak activity	Lower proportion		Higher proportion

Weekday Hot

Comparison of 10min Hot Soak Duration

Legend: ■ Las Vegas weekday ◇ EPA Weekday

Y-axis: **cumulative percentage < 30 minutes** (0% to 70%)

X-axis: **Time of day** (6-7AM, 7-8AM, 8-9AM, 9-10AM, 10-11AM, 11-12N, 12-1PM, 1-2PM, 2-3PM, 3-4PM, 4-5PM, 5-6PM, 6-7PM, 7-8PM)

Lower proportion hot soaks < 10 minutes until 5pm

Much lower mid-day`
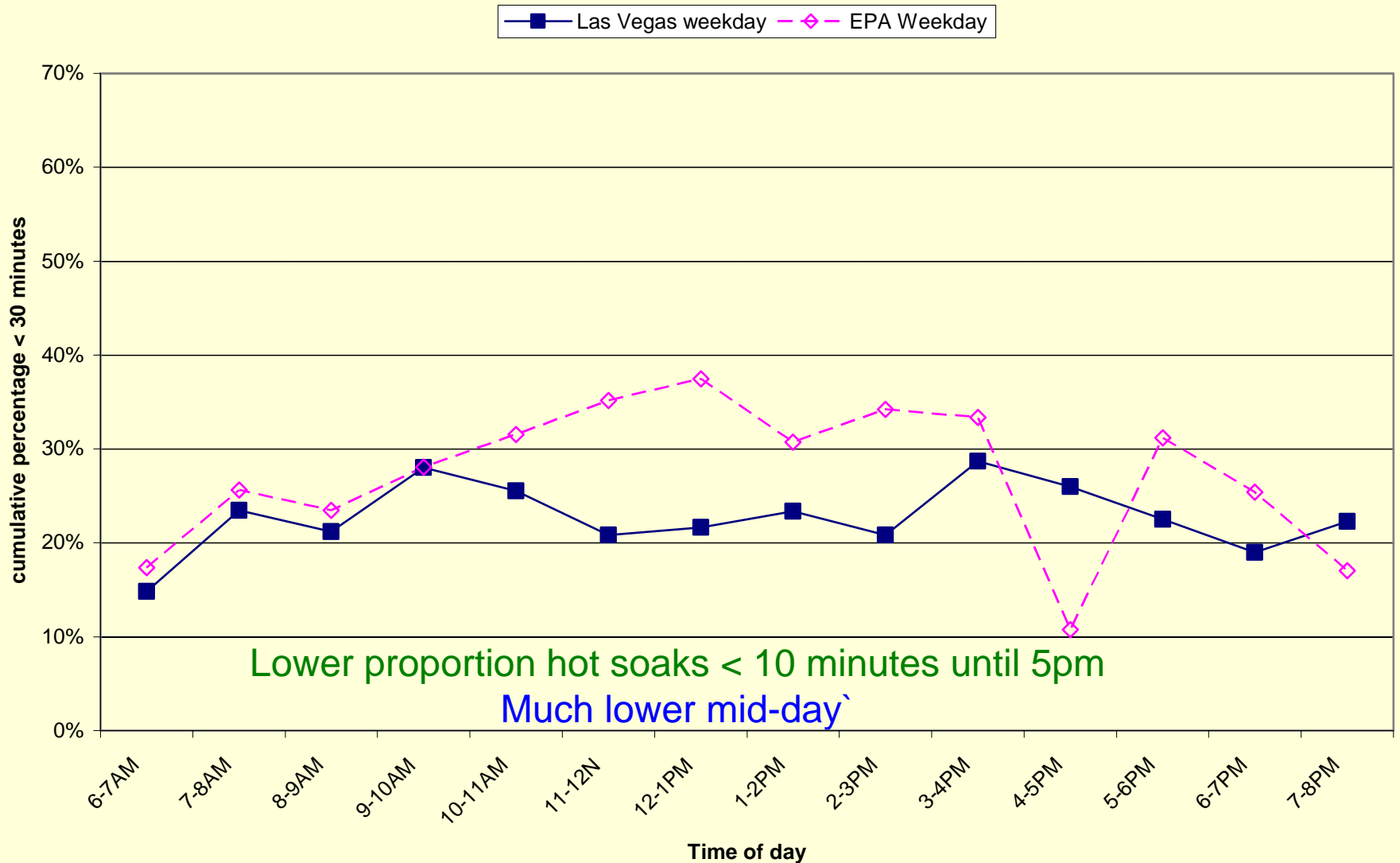
Weekend Hot

Comparison of 10min Hot Soak Duration

Legend: Las Vegas weekday ■ — EPA Weekday ◇

Y-axis: **cumulative percentage < 30 minutes** (0% to 70%)

X-axis: **Time of day** (6-7AM, 7-8AM, 8-9AM, 9-10AM, 10-11AM, 11-12N, 12-1PM, 1-2PM, 2-3PM, 3-4PM, 4-5PM, 5-6PM, 6-7PM, 7-8PM)

Generally Lower proportion hot soaks < 10 minutes until 5pm

Much lower until 10 am

WEEKDAY Comparison of Soak Duration less than 1hr

Weekday All soaks

Legend: Las Vegas, EPA

Y-axis: Culmulative % of Soak Duration (0% to 100%)

X-axis: Time of Day (6_7AM through 5_6AM)
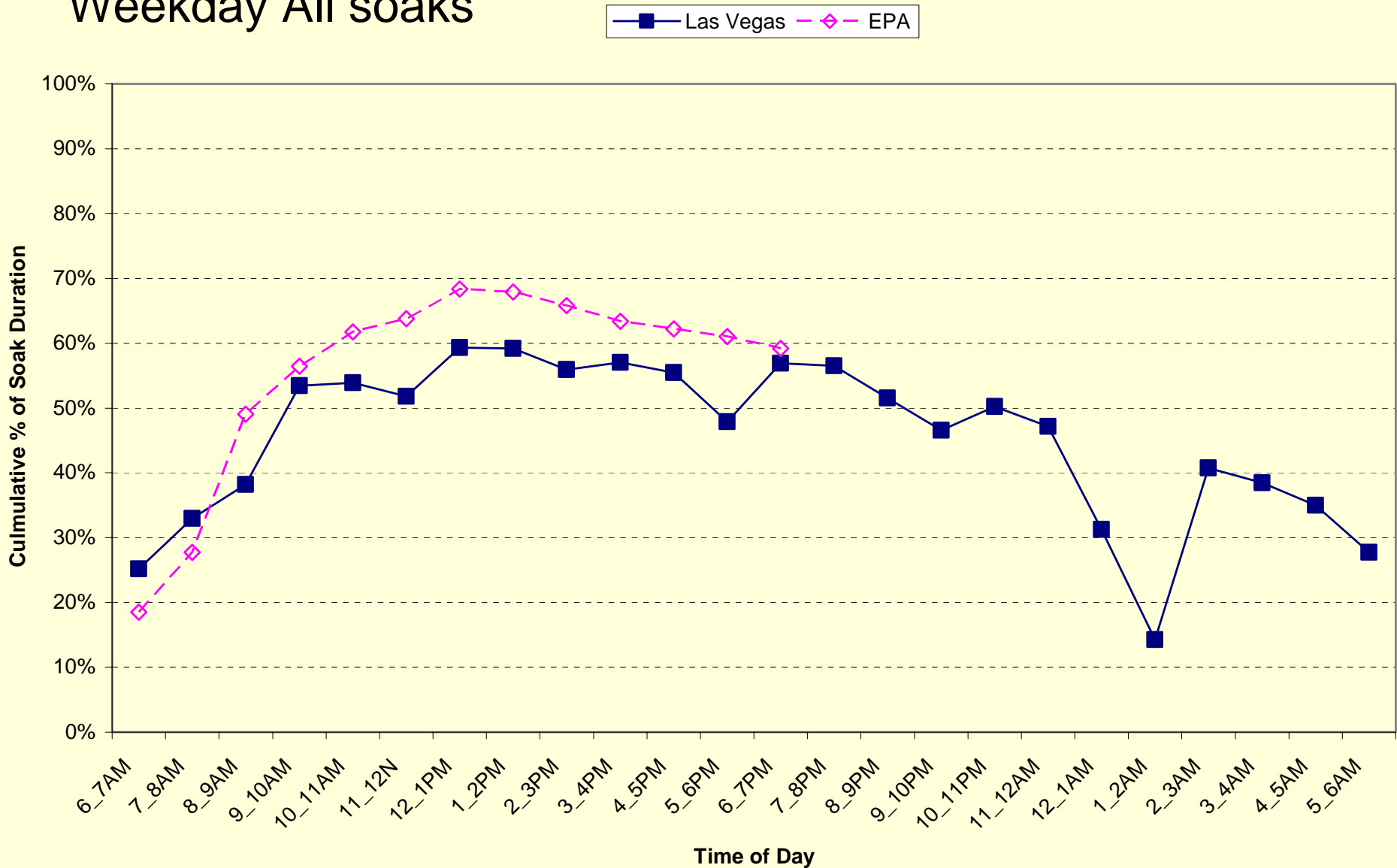
MOBILE6.2 soak distribution summary across hours of day

Data type and data file	Las Vegas result compared to EPA default
Cumulative soak length distribution *Soakdst.d*	Weekday, <u>lower %</u> 1 hour soaks than EPA Weekend, *<u>higher %</u>* 1 hour soaks than EPA
Cumulative soak length distribution *Soakdst.d*	Weekday, <u>lower %</u> % soaks < 3 hours compared to EPA Weekend, *<u>higher %</u>* soaks < 3 hours compared to EPA

Diurnal soak definition

- "Diurnal" soak is key-off period exceeding 2 hours during daytime

- Sunlight heats gasoline in vehicle – soaking emissions vary with daytime temperature

- Diurnal soaks = "long" soaks

Overall diurnal – Las Vegas lower than EPA until 9 pm

Diurnal soak activity
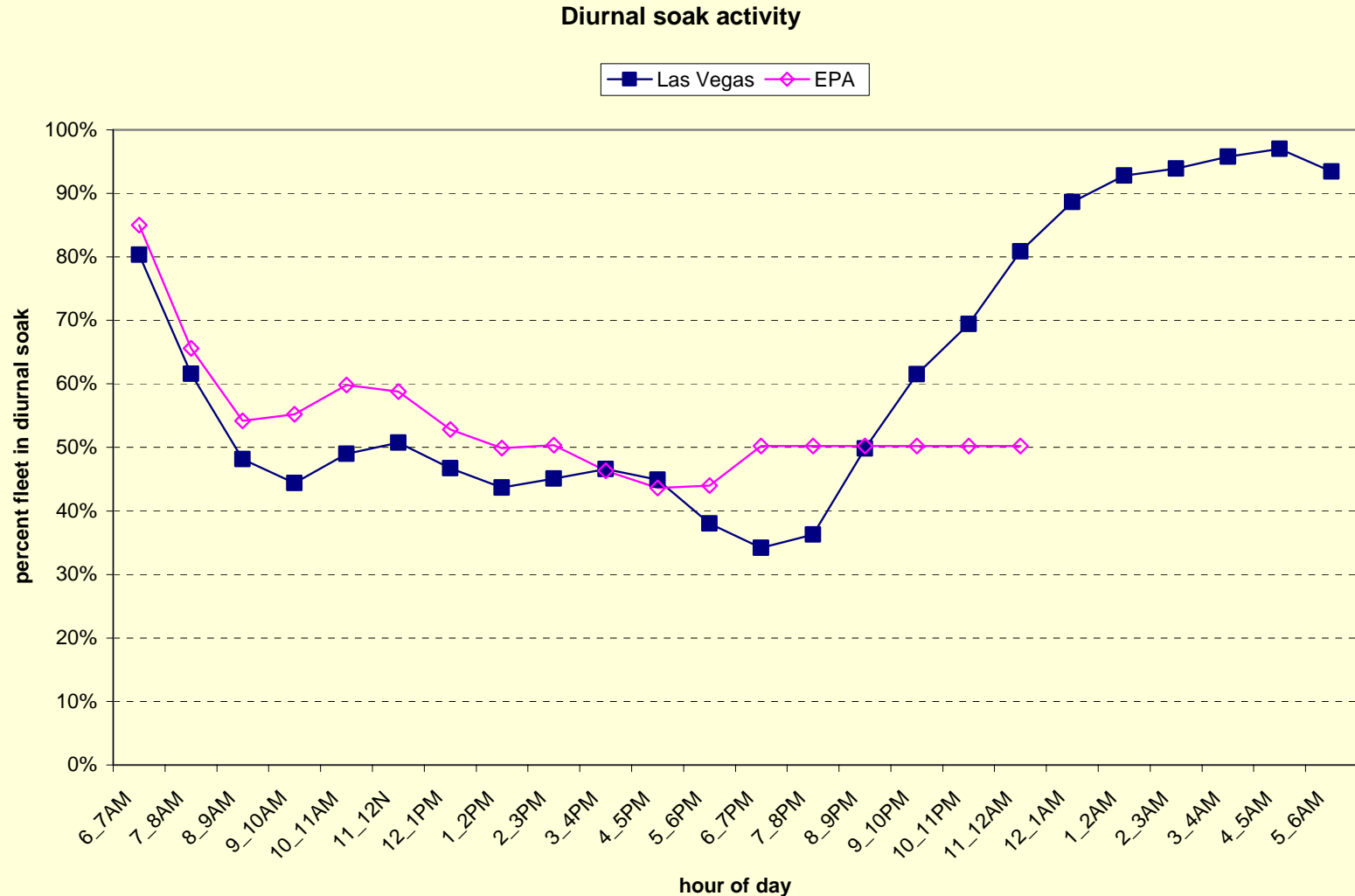
Las Vegas diurnal soak summary

Generally higher proportion 8-47 hour diurnal soaks

| Soak hour	6_7AM	7_8AM	8_9AM	9_10AM	10_11AM	11_12N	12_1PM	1_2PM	2_3PM	3_4PM	4_5PM	5_6PM	6_7PM
0--1	0.36%	0.57%	2.20%	9.03%	12.29%	10.01%	5.47%	4.50%	6.30%	8.37%	6.81%	5.88%	6.24%
1--2	0.72%	0.32%	0.43%	2.01%	8.40%	10.64%	7.75%	4.33%	3.55%	5.04%	6.67%	4.95%	4.65%
2--3	0.83%	0.60%	0.28%	0.44%	1.80%	7.42%	8.80%	6.03%	3.61%	2.66%	3.73%	4.88%	3.68%
3--4	1.83%	0.67%	0.55%	0.22%	0.43%	1.52%	6.36%	6.81%	5.32%	2.98%	2.05%	2.48%	2.78%
4--5	1.87%	1.59%	0.52%	0.57%	0.18%	0.37%	1.22%	5.63%	6.33%	4.57%	2.58%	1.45%	1.81%
5--6	3.41%	1.59%	1.38%	0.47%	0.52%	0.14%	0.28%	1.18%	5.23%	5.73%	4.01%	1.98%	1.23%
6--7	5.71%	2.82%	1.35%	0.94%	0.40%	0.40%	0.14%	0.23%	1.21%	4.72%	5.02%	3.23%	1.64%
7--8	7.62%	4.44%	2.11%	1.13%	0.70%	0.37%	0.36%	0.12%	0.24%	0.81%	3.42%	3.38%	1.92%
8--23	50.34%	42.83%	33.87%	24.39%	19.68%	15.47%	12.16%	10.39%	8.81%	7.21%	6.02%	5.63%	5.24%
24-47	5.86%	4.73%	4.16%	3.90%	3.48%	3.31%	3.22%	3.32%	3.28%	3.33%	3.33%	3.15%	3.68%
48-71	1.72%	1.46%	1.28%	1.26%	1.07%	1.04%	1.00%	1.15%	1.15%	1.16%	1.12%	0.98%	1.20%
72+	0.07%	0.00%	0.06%	0.03%	0.06%	0.06%	0.00%	0.00%	0.09%	0.00%	0.17%	0.05%	0.14%

EPA diurnal soak summary

Higher proportion <u>short</u> diurnal soaks

Soak hour	6_7AM	7_8AM	8_9AM	9_10AM	10_11AM	11_12N	12_1PM	1_2PM	2_3PM	3_4PM	4_5PM	5_6PM	6_7PM
0--1	0.89%	2.26%	6.34%	16.68%	21.66%	11.00%	6.27%	5.19%	8.60%	7.94%	9.40%	11.33%	13.21%
1--2	0.71%	0.47%	0.40%	0.40%	2.17%	10.03%	11.36%	10.41%	8.11%	7.83%	5.79%	6.46%	7.89%
2--3	1.60%	1.03%	0.82%	0.76%	2.42%	6.29%	6.79%	6.89%	6.55%	6.29%	5.60%	5.66%	6.65%
3--4	2.71%	1.72%	1.30%	1.14%	2.52%	4.51%	4.70%	5.00%	5.28%	5.02%	4.95%	4.69%	5.37%
4--5	3.92%	2.47%	1.81%	1.52%	2.53%	3.45%	3.49%	3.80%	4.26%	4.00%	4.17%	3.77%	4.22%
5--6	5.12%	3.24%	2.31%	1.87%	2.48%	2.75%	2.72%	2.98%	3.43%	3.18%	3.38%	2.97%	3.26%
6--7	6.21%	3.95%	2.76%	2.18%	2.39%	2.26%	2.18%	2.39%	2.76%	2.52%	2.67%	2.30%	2.49%
7--8	7.07%	4.56%	3.14%	2.43%	2.27%	1.89%	1.78%	1.94%	2.22%	2.00%	2.06%	1.76%	1.88%
8--23	56.64%	45.49%	34.48%	27.07%	18.26%	11.67%	10.08%	9.67%	8.80%	7.32%	5.59%	5.02%	5.24%
24-47	0.14%	0.42%	0.83%	1.17%	3.12%	3.91%	2.79%	1.52%	0.34%	0.21%	0.01%	0.02%	0.02%
48-71	0.00%	0.00%	0.00%	0.00%	0.04%	1.03%	0.63%	0.11%	0.00%	0.00%	0.00%	0.00%	0.00%
72+	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

When vehicles "on" or short soak

Running & "hot" soak activity
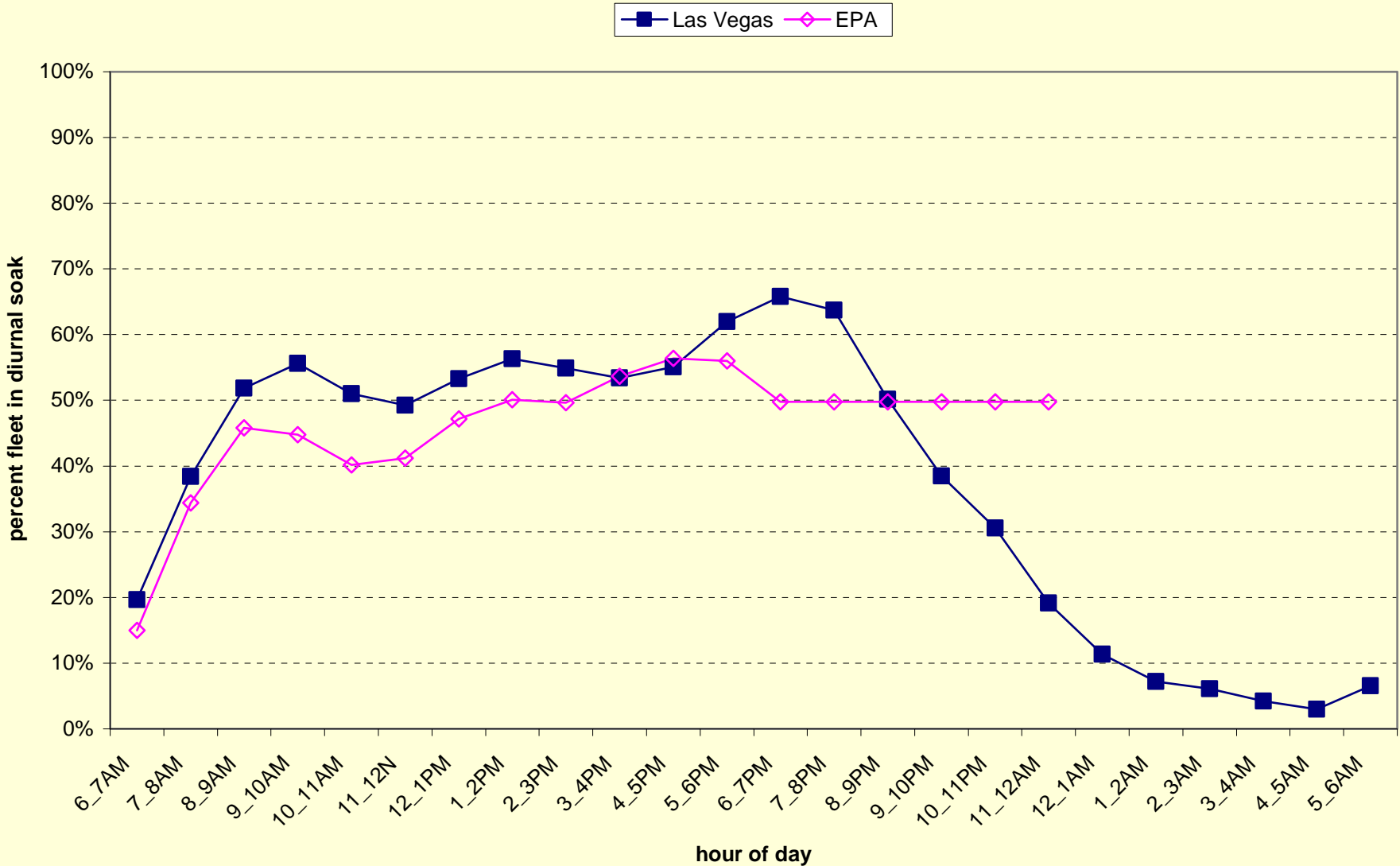
Study	EPA 3 city	CARB	Knoxville	Las Vegas
Sample size	245	96	377	349
Fleet type	Private car & light truck	Private car & light truck	Private car & light truck	Private car & light truck
Weekday car start/day	7.3	7.1	5.7	5.5$\pm$3.9
Weekday truck start/d	8.1	n/a	6.2	5.5$\pm$3.1
Weekend car start/day	5.4	5.9	4.1	5.7$\pm$4.4
Weekend truck start/d	5.7	n/a	4.7	4.7$\pm$2.5

Numerical weekday summary

Item: Las Vegas compared to EPA 3-city study	Las Vegas	EPA
Fewer weekday starts/day Mixed weekend	5.5c – 5.5t 5.7c – 4.7t	7.3c – 8.1t 5.4c – 5.7t
Weekday AM peak starts Weekday PM peak starts	7 am 5 pm	8 am 3 pm
More short (< 10 min) trips	50%	25%
Fewer short hot soaks < 10 min; similar evening	Mid-day 25% pm 30%	Mid-day 32% pm 30%
Lower proportion of short (1-2hr) diurnal soaks	6%	8%
Higher proportion of very long (8-47 hr) diurnal soaks	5% 8-23 17% 24-47	1% 8-23 9% 24-47

Why fewer starts and more short trips in Las Vegas? – our guesses

- <u>Newer, more compact urban area</u> – more areas master-planned.
  - Shorter distances to services?
  - Convenient auto parking?
- <u>Climate</u> –
  - more likely to use cars for short trips in hot weather?
- <u>Demographics and mass transit infrastructure</u> –
  - low proportional use of public transportation?
  - <u>"Car culture" habits</u> of residents?

Speculation - What might this mean for mobile source emissions?

MOBILE 6.2 runs not completed yet!!

Fewer starts → **Lower** <u>total</u> emissions

More short trips → higher *proportion* of CO

Higher proportion long soaks → higher *proportion* VOC

More short trips → **Lower** *proportions* of NOx

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